U.S. DEPARTMENT OF ENERGY - BONNEVILLE POWER ADMINISTRATION

Memorandum

DATE : April 9, 1992

FROM : Mike Street,
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SUBJECT : Fault Locator Coupling Issues

TO : PSC District Engineers

Periodically I have received calls from PSC maintenance district people with questions about the fault locator outdoor coupling equipment. The purpose of this memorandum is to discuss fault locator coupling issues and to give you a guide of what to look for when inspecting fault locator coupling equipment.

While some District PSC personnel have worked extensively on the Fault Locator outdoor equipment, others have not. Thus, the following information includes basic fundamentals of fault locator coupling before going on to more detailed information for the sake of good continuity.

Fault Locator History

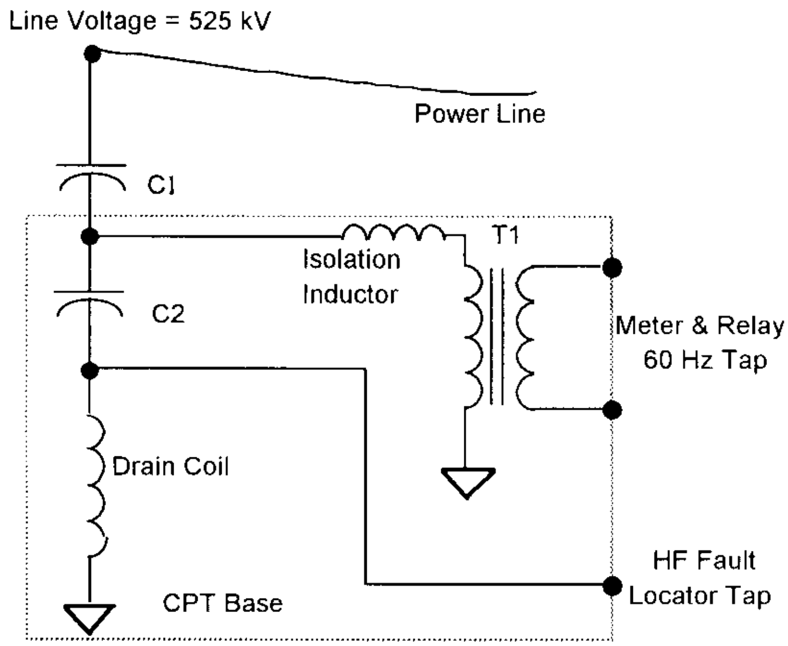
BPA involvement in traveling wave fault location dates back to the 1950's. The fault locator system which preceded the FLAR (Fault Locator Acquisition Reporter) system was called the Type-B fault locator. FLAR remotes with addresses of 1 through 21 were originally Type-B fault locator sites. Most of the Type -B remotes were installed circa 1968 - 1972. The FLAR remotes which replaced the old Type-B remotes were installed circa 1986 to 1989. The original outdoor coupling schemes for the Type-B remotes remained in service for the replacement FLAR remotes. During the early days of the fault locator, BPA used several different coupling schemes. The typical approach was to couple powerline fault transients via the Power Line Carrier(PLC) tap of a Capacitive Potential Transformer(CPT) although other coupling methods were used. I have found that some of these other methods, which are discussed later in this memo, are still in service and have resulted in poor fault transient coupling.

Fault Locator Coupling Techniques

Fault and switching transients contain high frequency components in the spectrum above approximately 70 kHz. These transients will have rise times in the range of 2 to 10 μseconds. Thus, the preferred fault transient coupling method is via the high frequency PLC tap of a CPT which is illustrated by Figure 1. The BPA fault locator transient detector "looks" for fault transient energy in the spectrum of about 70 to 350 kHz. BPA uses many different manufacturer's CPT's. Currently the most common are Trench and Haeffly. At older stations you might find units made by General Electric, Westinghouse, Hitachi or Brown Boveri in addition to Trench and Haeffly. However, all CPT's use the same general configuration shown in Figure 1.

You will find CPT's also called Capacitive Voltage Transformers (CVT) and Coupling Capacitor Voltage Transformers (CCVT).

CPT's have two outputs. These are a 60 Hz output for meter and relay applications and the high frequency (HF) output for PLC and Fault locator coupling applications.



Capacitive Potential Transformer - Basic Configuration
Figure One

Meter/Relay 60 Hz Output

At 60 Hz, the Drain coil has a very low impedance compared to the reactance of C2 and thus effectively connects the low side of C2 to ground. C1 and C2 form a capacitive divider which divides down the line voltage (525 kV$\div\sqrt{3}$ = 303 kV) and applies it to the primary of intermediate transformer T1. T1 has a turns ratio about 100 to 1 and, therefore, presents a relatively high impedance load to the C1, C2 capacitive divider. (Typical capacitor values of a CPT such as the Trench model TEHM are C1 = 5400 pf and C2 = 125,500 pf.)

The voltage at the capacitive tap point is about 12 kV for a 500 kV CPT. The intermediate transformer usually has two tapped secondary windings. Typically, the intermediate transformer output voltage at the meter/relay taps is about 120 VAC with a tap at 69 VAC. Transformer T1 has a bandwidth of only 20 kHz and thus is not suitable for fault locator coupling. The isolation inductor isolates T1 from the capacitive divider at high frequencies while passing the 60 Hz signal. A shorting switch (not shown) across the T1 primary will disable the 60 Hz output without disrupting the high frequency output. Some CPT manufacturers place the isolation inductor such that it can be connected in parallel with the

T1 primary by closing a switch to ground. Either way a maintenance person can disable the 60 Hz output without affecting the HF output.

High Frequency Output

The equivalent series capacitance of C1 and C2 in series (C_{total}) will be between 3500 and 7400 pf, depending on CPT manufacturer. The drain coil inductance range is typically 25 to 50 mH. You will notice that C_{total} and the drain coil form a High-Pass Filter. This HPF will pass the high frequencies in the fault transient spectrum but will reduce the 60 Hz voltage to a safe level. Table 1 illustrates the 60 Hz voltages you should find on the coax cable coming into the Fault Locator CPT coupling box from a CPT connected to a 500 kV line.

Drain Coil Current Rating

A 60 Hz current will flow through a CPT's capacitance and drain coil to ground. Because the CPT capacitive reactance is significantly larger (330 kΩ to 600 kΩ) than the drain coil reactance (19Ω), the value of this continuous current is proportional to total CPT capacitance as follows:

$$i_{DrainCoil} = \frac{e_{line\_Gnd}}{x_c} = \frac{e_{line-line}}{\sqrt{3}} \times \frac{1}{x_c} = \frac{e_{line} \times 2\pi \times 60Hz \times C}{\sqrt{3}}$$

You can actually measure this current by connecting an AC ammeter across the coax cable which connects to the drain coil. Because the ammeter resistance will be significantly lower than the drain coil reactance(19 Ω), the CPT 60 Hz current will shunt through it. Table 1 shows the calculated 60 Hz continuous current for various types of CPT's.

Usually, a CPT has been equipped with a factory installed drain coil which is designed to handle that CPT's continuous current. The possibility exists that a CPT used for fault locator coupling has a retro-fitted drain coil. Troutdale PSC maintenance found an example of this at Ostrander. They found a GE Type 4CL12 drain coil (Now manufacturer discontinued) installed in several of the Hitachi CPT's used at Ostrander Sub. The drain coils had burned up and were open which resulted in higher than expected voltages (≈ 125 VAC) on the coax coming into the CPT coupling units. Much speculation occurred on what caused the drain coils to burn out. We finally concluded, after a post-mortum examination) that the #32 wire used in these models couldn't handle the .84 amps flowing through them.

PSC Parts (MMED-11) has GE Type 4CL14D replacement drain coils available in the event you discover a burned out drain coil in a CPT used for fault locator coupling.

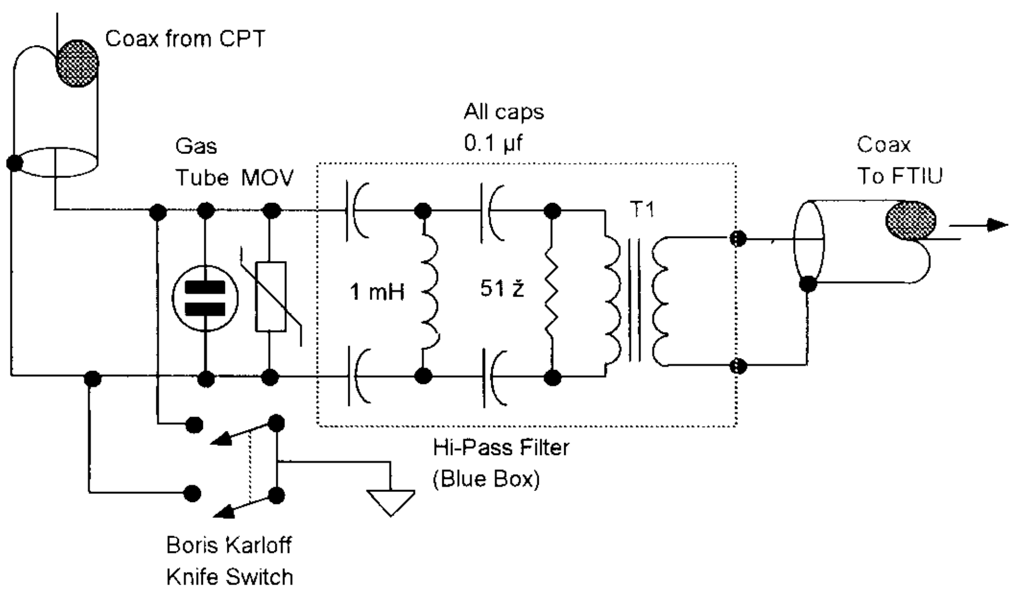
CPT Type	Ctot	L drain coil	Z drain coil	Cont. Current	V drain coil
Haefely CVE 575	3600 pf	50 mH	19 ohms	.41 amps	7.8 volts
Trench TEHM	5200 pf	45 mH	17 ohms	.6 amps	10 volts
Hitachi POEGFLV	7360 pf	25 mH (*)	12 ohms	.84 amps	10 volts
Hitachi POEGFLV	7360 pf	50 mH (**)	19 ohms	.84 amps	17volts

(*) GE type 4CL14D drain coil
(**) GE type 4CL12C drain coil

60 Hz Drain Coil Voltages for Various CPT's Connected to 500 kV lines
Table 1

CPT Coupling Box

There are two versions of CPT coupling Box. The original CPT Coupling Box, illustrated by figure 2, was designed and fabricated circa 1970. You will find this model at the original fault locator sites. Attached is a copy of BPA DWG. 188793-KCT-D REV. 7 which gives full details of this unit. Much of the design philosophy for this unit is lost in antiquity. Questions such as, why the design uses a balanced filter connected to the CPT coax cable and two pole shorting switch may never be answered.

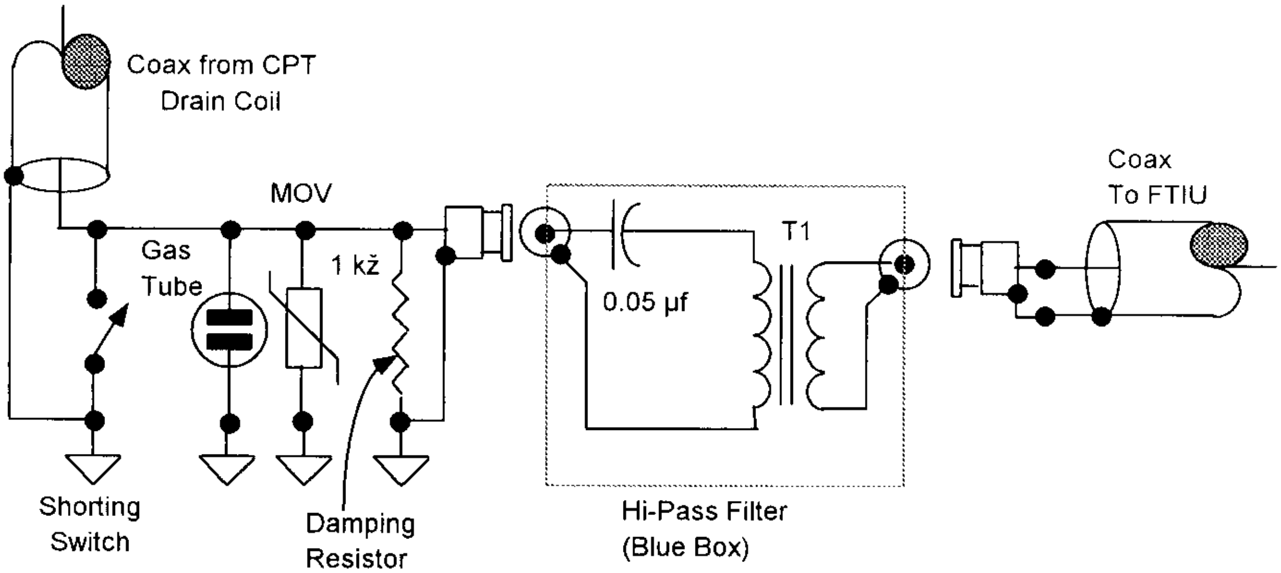


CPT Coupling Unit - Original Version
Figure 2

When doing a fault locator site inspection, especially when investigating problems of high or low number of detected transients, be sure to make a visual inspection that the MOV and gas tube are intact. Damaged MOV's will have a discoloration or in extreme cases will have cracks in the red epoxy coating. Damaged gas tubes will have cracked glass or heavy black deposits inside the glass. Some gas tubes may normally have a slight dark deposit inside the glass.

Replacement MOV's and gas tubes are available from PSC Parts (MMED-11).

The newer version CPT coupling unit is fully described by BPA DWG. 169759-ECC, Sh 1, which is attached. You will usually find these units installed at substations with fault locator remotes installed after 1992. Some stations with older remotes also have the newer version of coupling unit. Figure 3 is a simplified diagram of the new version coupling unit.



CPT Coupling Box - New Version
Figure 3

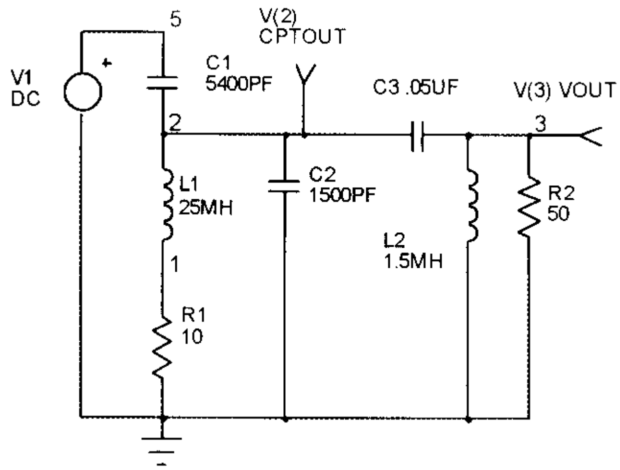
The new version CPT coupling box employs a larger MOV and has a simpler unbalanced filter. Also, the filter coupling capacitor has a higher (2500 volt) breakdown voltage compared to the capacitor is the older version filter. *The new filters and associated front panels are available from PSC Parts (MMED-11) in the event the filter in the older version has burned out and must be replaced.*

Another addition to the new coupling box design is the addition of the 1000 ohm damping resistor. This resistor dampens the 4 to 5 kHz resonance of the drain coil inductance with the filter input capacitor.

CPT Coupling Circuit Analysis

The following is an analysis of the fault locator coupling circuitry using a circuit analysis program by Intusoft®. The model illustrated in Figure 4 below is for the new fault locator coupling box without the 1000 ohm damping resistor. C1 represents the total CPT capacitance from the line to the drain coil, L1. R1 is the drain coil's equivalent series resistance. The C1 value actually will be between 3500 and 7400 pf. The analysis uses a nominal value of 5400 pf. C2 is the capacitance of the MOV, C3 is the high-pass filter coupling capacitor and L2 is the magnetizing inductance of the coupling transformer. R2 is the 50 ohm load provided by the

FTIU via the coupling transformer. V1 represents an "imaginary sweep generator" attached to the power line. V(2) is a "test point" for the CPT output and V(3) is the high-pass filter output to the control house.



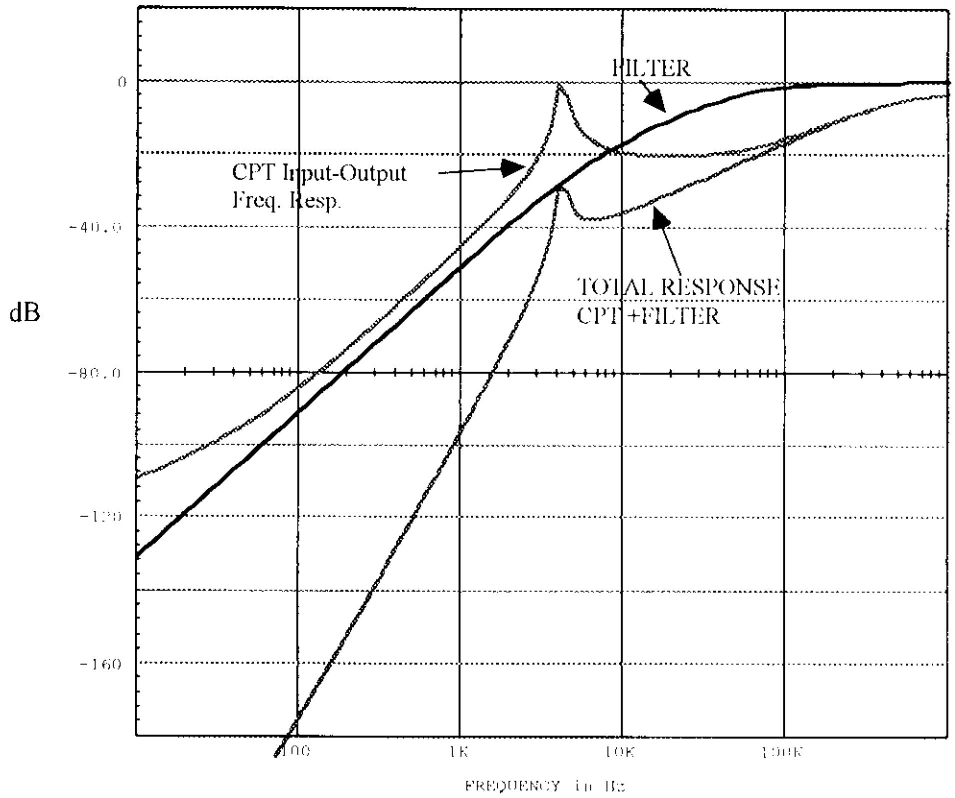
Equivalent Circuit of CPT and Filter without Damping
Figure 4

Figure 5 below illustrates the calculated frequency response of the CPT and the Coupling Unit high-pass filter. The CPT acts as a two pole high-pass filter. The lowest plot is the composite of the two cascaded filters.

Note the resonant peak at about 3.5 kHz. Many PSC maintenance people have called to report voltages of 30 to 80 volts in the coupling box on the coax from the CPT which is much higher than the voltages predicted in the analysis of Table 1. The reason for this higher measured voltage was due to this resonant peak which did not attenuate the power frequency harmonics in the region of 3500 Hz. This phenomenon also occurs in the old style coupling units as well, since the equivalent filter input capacity is 0.05 µf (two 0.1 µf caps in series).

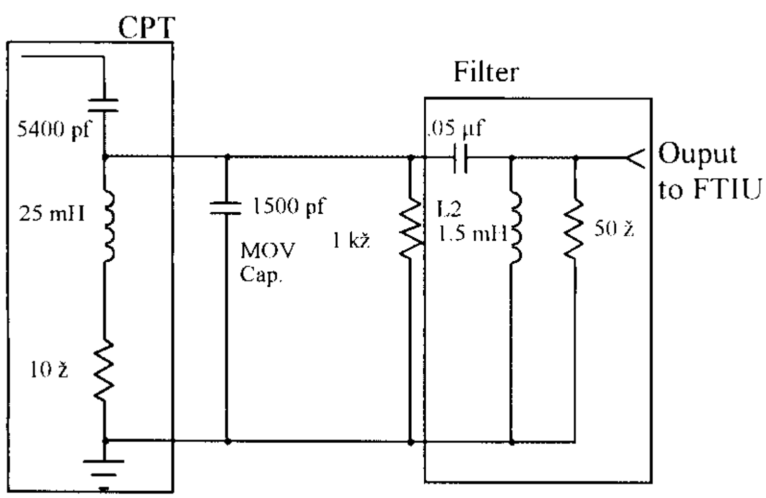
To correct the resonance problem, the new coupling box includes a 1000 ohm , 3 watt resistor across the coax from the CPT. This resistor dampens (or "de-Q's) the 3.5 kHz resonance, but has no effect in the higher transient frequency range.

To confirm that an excessively high voltage in an older model coupling unit is due the resonance phenomenon, disconnect the BNC cable connect to the blue filter box input and note that the measured voltage decreases. If resonance is the culprit, connect a 1000 ohm, 2 - 3 watt resistor across the same terminal block to which the to red MOV attaches.



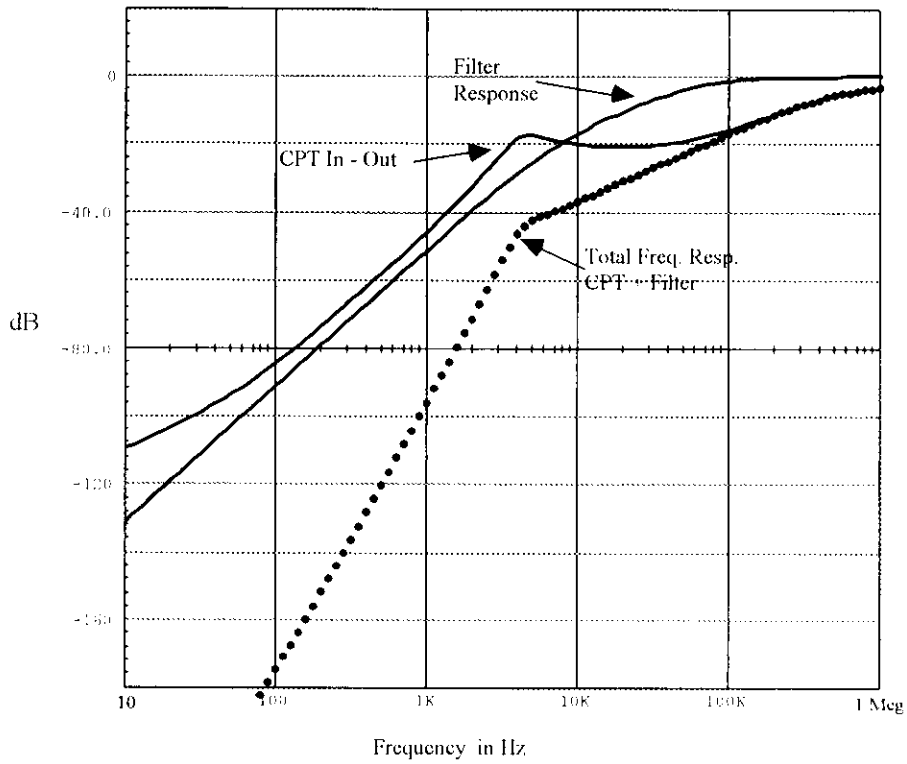
CPT and Filter Frequency Response without Damping Resistor
Figure 5

Figure 6, below illustrates the coupling box circuit *with* the dampening resistor.



Equivalent Circuit of CPT and Filter with Damping (R4=1000 Ω)
Figure 6

Figure 7 below illustrates the frequency response of the CPT and high-pass filter with the damping resistor added essentially in parallel with the drain coil and filter input capacitor combination. Notice that the damping resistor reduces the resonant peak by nearly 20 dB and that no resonant peak shows up in the total response from line to CPT.

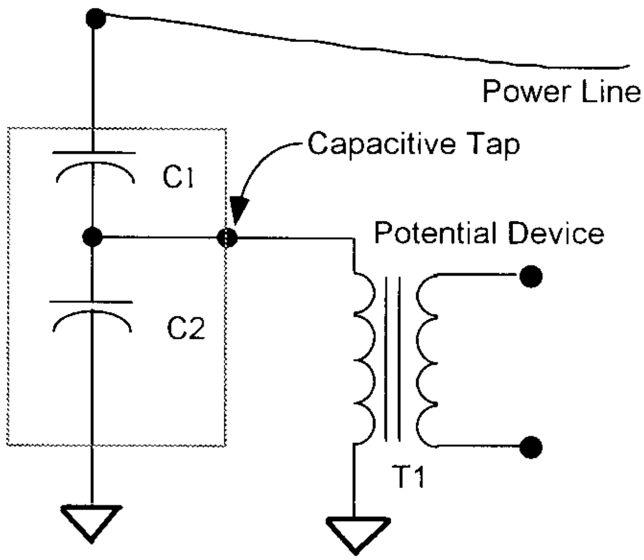


CPT and Filter Frequency Response with Damping Resistor
Figure 7

Other Coupling Configurations

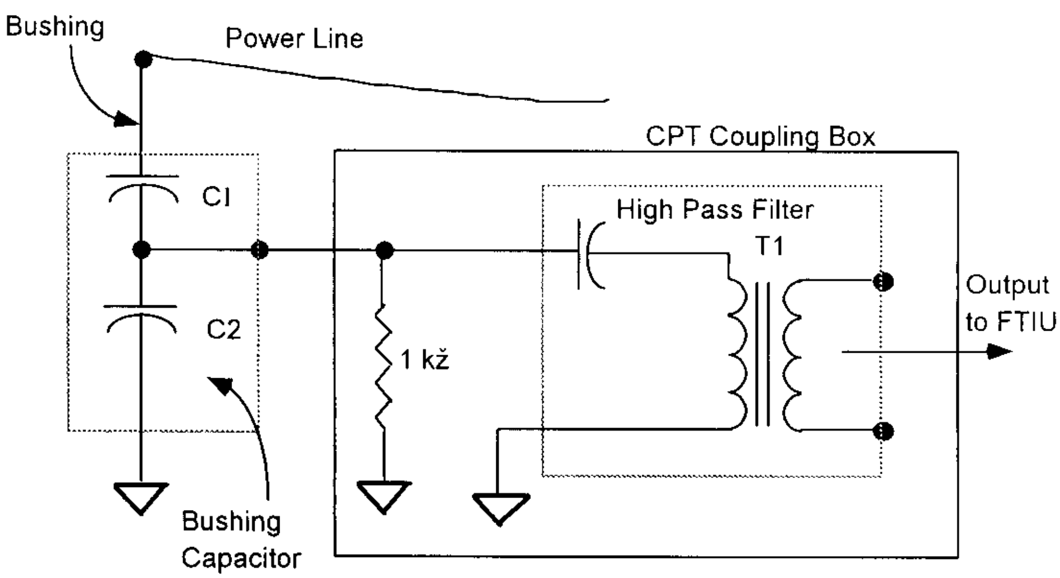
While the standard fault locator coupling method is coupling via the CPT high frequency output, in the past other coupling methods were employed.

Bushing Capacitor
One of these approaches was to use the bushing capacitance of transformers and circuit breakers. Bushing capacitors usually connect to external transformers known as *Potential Devices* and are typically used for hot line indications. Figure 8 illustrates a bushing capacitor coupling arrangement. The value of the bushing-to-capacitive tap capacitance, C1, is in the range of 200 to 400 pf while the tap-to ground capacitance, C2, is 3000 to 6000 pf.



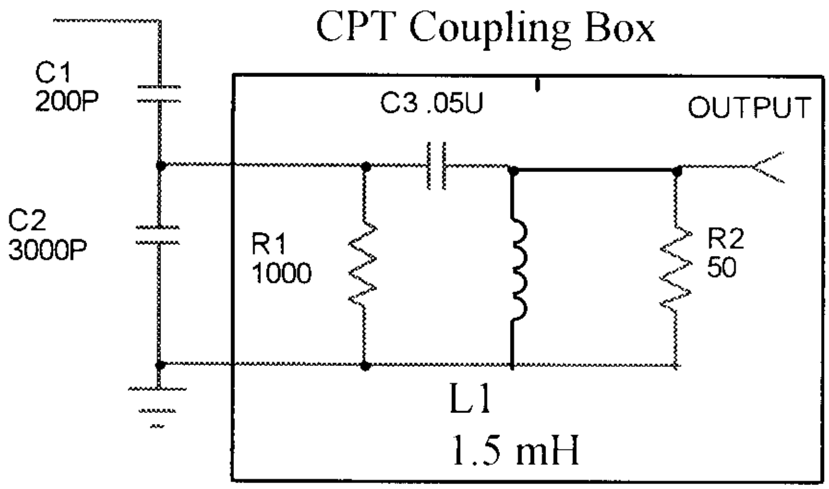
Bushing Capacitor Normally used with Potential Device for "Hot Line" Indication
Figure 8

Typically, capacitance tap fault locator coupling, as is illustrated by figure 9, was only employed on 230 kV lines. Because the open circuit capacitive tap voltage is about 9 kV, the output must be loaded by the 1000 Ω resistor to keep the 60 Hz voltage inside the coupling box down to a safe level. Typical values would be in the 10 to 20 volt range.

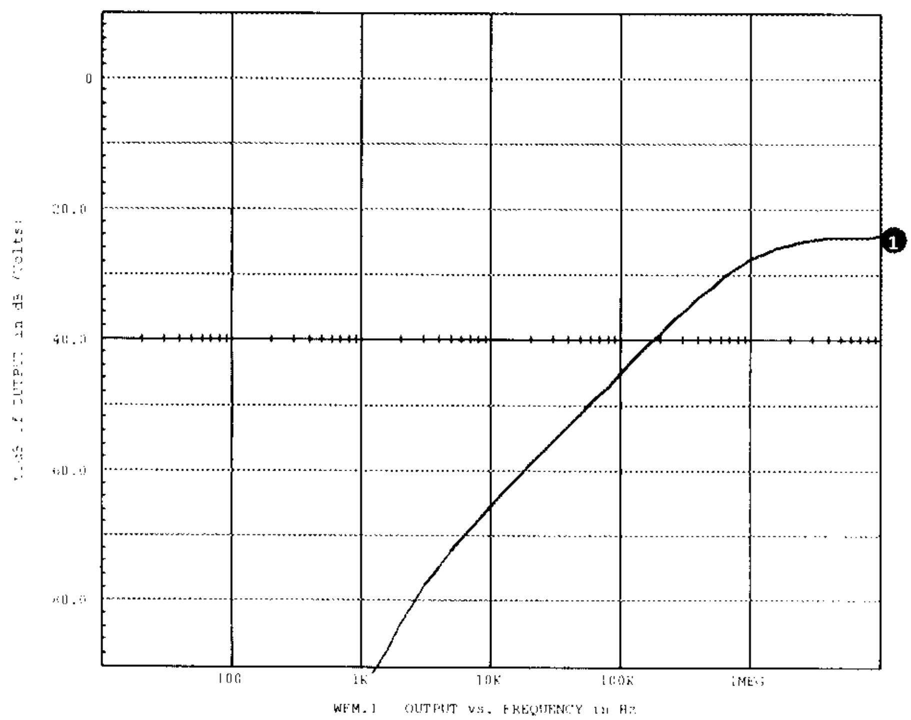


Bushing Capacitor Used For Fault Locator Coupling
Figure 9

BPA experience with this type of coupling is that it does not provide adequate sensitivity to transients of marginal level. The following analysis will illustrate the reason for this. Figure 10 shows the analysis model. Figure 11 is the frequency response. Note that the attenuation in the range of 100 to 350 kHz for this coupling is down a nominal 40 dB as compared to 16 dB with CPT HF tap coupling.



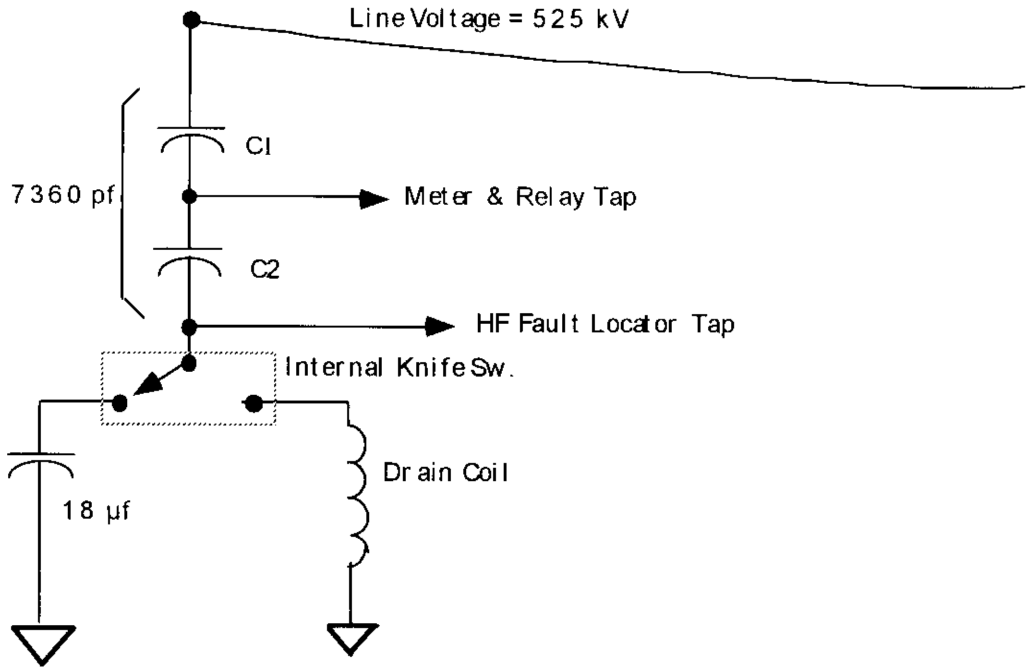
Bushing Capacitor Equivalent Circuit
Figure 10



Bushing Capacitor Coupling Frequency Response
Figure 11

HF Taps That Aren't Really HF Taps

A problem that I have run across in the last year or so, is the case where CPT coupling appears to be employed, but that a drain coil is not installed. If your substation uses Hitachi CPT's, you may have this situation. Hitachi Type POEGFLV CPT's were installed in the early 1970's which used a capacitive divider rather than the typical L-C high pass arrangement. Figure 12 illustrates this arrangement.

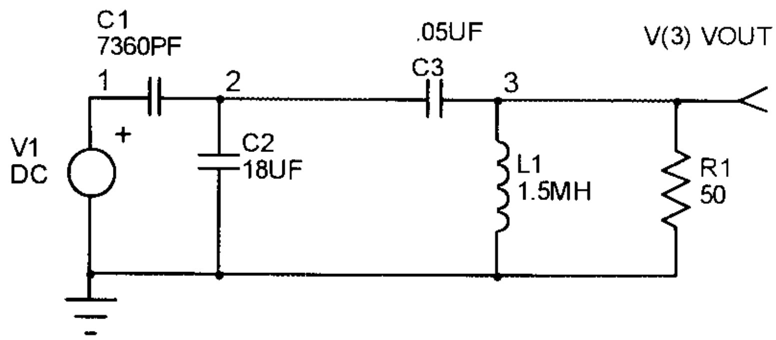


Hitachi CPT Circuit Diagram
Figure 12

Some Hitachi CPT's were installed with a large value (≈18 μf) oil capacitor connected in the place where a drain coil typically was installed. The name plate diagram actually indicated the SPDT knife switch to allow selecting a capacitor or an optional drain coil. With the 18 μf capacitor in place, the voltage in the CPT coupling unit is about 125 VAC. This arrangement is undesirable for the following reasons:

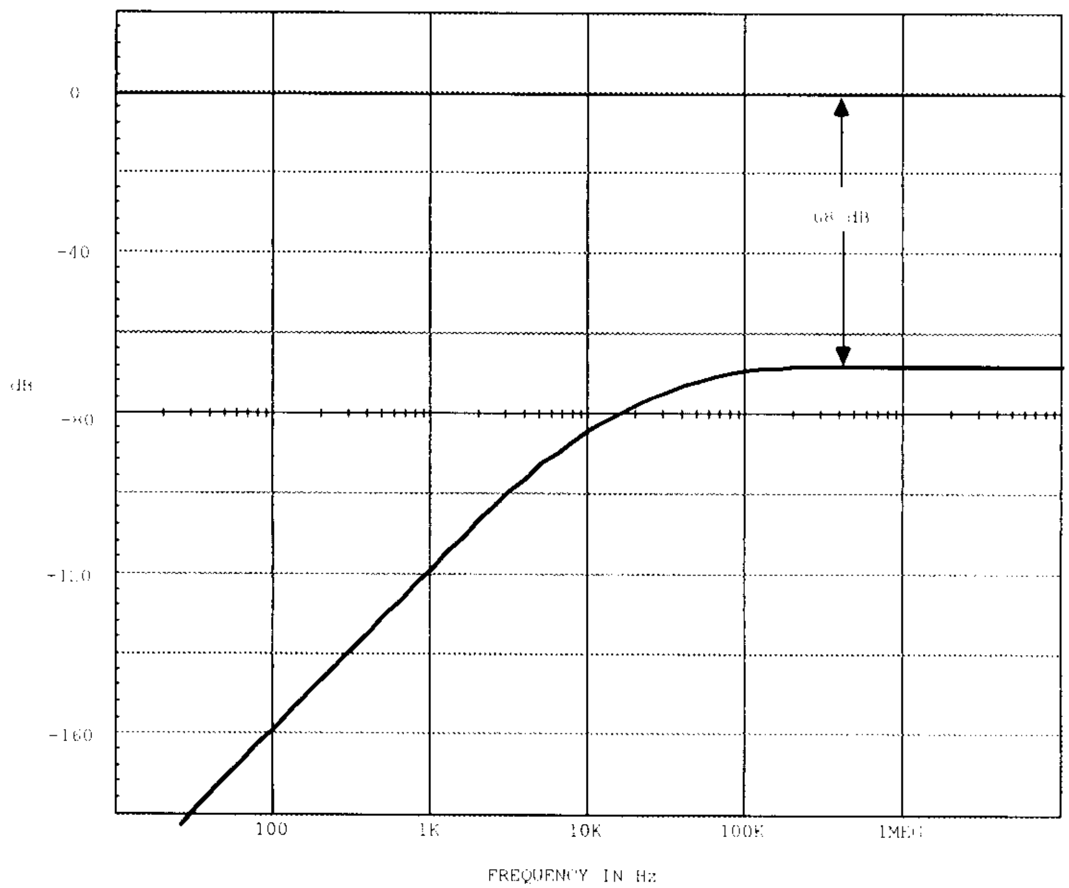
1. Hazardous voltage (125 VAC) in the Fault locator coupling unit.
2. Causes stress on the 130 VAC MOV.
3. Excessive fault transient attenuation causes poor fault locator sensitivity.

Figure 13, below, is the analysis model for the fault coupling circuit illustrated by Figure 12. Figure 14 illustrates the corresponding frequency response of this arrangement.



Hitachi CPT Analysis Model
Figure 13

Note that the voltage divider formed by C1 and C2 has a division ratio of -68 dB. Compare this with the CPT configuration employing a drain coil in lieu of C2 (Figure 7). Note that with the drain coil, the response is down a nominal 20 dB while with the 18 µf capacitor the response is down an additional 40 dB. This explains why substations using CPT's having the configuration described in figures 12-14 will have poor fault locator sensitivity.



Hitachi CPT Frequency Response
Figure 14

Summary

This paper has discussed the various methods BPA has used down through the years for coupling fault transients from power lines to Fault Transient Interface unit (FTIU) part of the BPA traveling wave fault locator system. While the preferred coupling method employs a CPT with a high frequency output, previous installations used bushing capacitive taps and CPT's configured as large ratio capacitive dividers. As PSC personnel do maintenance on fault locator remotes, they should inspect the outdoor coupling equipment for evidence that undesirable coupling methods were employed for the initial installation.